

Variable	Mean	SD	Min	Max
Age	34.5	10.2	21	55
Gender	Male	Female		
Marital status	Married	Single		
Education	High school	College		
Occupation	Manager	Worker		
Income	Low	High		
Health status	Good	Poor		
Stress level	Low	High		
Life satisfaction	Low	High		
Resilience	Low	High		
Optimism	Low	High		
Self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		
Perceived resilience	Low	High		
Perceived optimism	Low	High		
Perceived self-efficacy	Low	High		
Perceived social support	Low	High		
Perceived stress	Low	High		
Perceived life satisfaction	Low	High		

This invention relates to an apparatus for monitoring performance of a water purification system. Particularly, the invention relates to a monitoring unit or test cell for monitoring fouling and biofouling of semi-permeable reverse osmosis membranes utilized in water purification systems. The invention also extends to the use of such a monitoring unit in evaluating various operating parameters of such a system, and to a water purification system including such a monitoring unit or test cell.

Those who are familiar with the industry will appreciate that a reverse osmosis water purification system provides for cleaning an impure aqueous solution by forcing the solution through a semi-permeable membrane to obtain a substantially pure aqueous solution. More particularly, an impure aqueous solution is generally pumped, under pressure, through the semi-permeable membrane, which is designed for retaining impurities such as organic and inorganic substances, thereby effecting passage only of the substantially pure aqueous solution through the membrane.

2

time, the membrane's efficiency decreases due to adsorption of impurities on the membrane surface. Moreover, uncontrolled microbiological growth in a feed fluid tank, pipelines or on the membranes themselves can result in severe biofouling of the semi-permeable membrane. If this situation is detected in time, the membranes can be cleaned, for example by mechanical or chemical treatment processes. However, a major problem associated with this type of technology is the lack of methodology by which fouling or biofouling of the membrane is detected and monitored. If the membrane is not cleaned in time, the membrane can be damaged permanently, unavoidably resulting in downtime of the system, associated production losses, and expensive maintenance and replacement costs for replacing the membrane.

Apparatus have been developed in an attempt to detect fouling of the semi-permeable membrane in time, but these all suffer from one or more disadvantages. One such apparatus provides for monitoring fouling of the membrane, and hence performance of a reverse osmosis water purification system, by comparing electrical conductivity of an impure aqueous solution at an inlet side of the membrane with that of a substantially purified aqueous solution at an outlet side of the membrane.

Another known apparatus involves utilizing a centrifugal pump for increasing fluid pressure of a feed fluid to a value exceeding that of its osmotic pressure. Fouling of the semi-permeable membrane and performance of the water purification

detecting fouling of the membrane in time, the situation being such that by the time fouling is eventually detected, the membrane is already damaged.

Object of the invention

- 5 It is accordingly an object of the present invention to provide a novel apparatus for monitoring the condition of a semi-permeable membrane, especially of the type utilized in a reverse osmosis water purification system, that will overcome or at least minimize some of the disadvantages associated with known apparatus of this kind.

10

It is a further object of the invention to provide for use of such an apparatus for evaluating and comparing different operational parameters of a reverse osmosis water purification system.

- 15 It is yet a further object of the invention to provide a water purification system including the novel apparatus for monitoring the condition of a semi-permeable membrane.

Summary of the invention

- 20 According to the invention there is provided a monitoring unit for monitoring the condition of a semi-permeable membrane, the monitoring unit comprising a flow chamber having an inlet for permitting ingress of a feed fluid into the flow chamber, the arrangement being such that the membrane is at least partly

supported in the flow chamber; at least one fluid outlet arranged in fluid communication with the flow chamber for permitting egress of fluid from the monitoring unit after having passed through the membrane; and an inspection window for permitting visual inspection of the semi-permeable membrane.

5

The monitoring unit particularly may be adapted for monitoring fouling of the semi-permeable membrane. For the purpose of this specification, "fouling" will be interpreted to include organic fouling, inorganic fouling, bio-fouling or the like accretion of impurities such as precipitates, scale or the like particulate matter on
10 a surface of the semi-permeable membrane. Furthermore, the term "feed fluid" will be interpreted to mean substantially impure fluid introduced into the flow chamber, whereas the term "fluid" will mean substantially pure fluid having passed through the semi-permeable membrane and exiting the monitoring unit.

15 The flow chamber may include a feed fluid outlet for permitting at least partial through-flow of the feed fluid through the flow chamber. In particular, cross-flow conditions may apply in the flow chamber. The flow chamber may be dimensioned such that a fluid pressure interval is defined intermediate the feed fluid inlet and the feed fluid outlet. Particularly, fluid pressure at the feed fluid
20 outlet may be less than that at the feed fluid inlet such that, in use, the feed fluid partly exits through the feed fluid outlet of the flow chamber and in part passes through the semi-permeable membrane.

The monitoring unit also may comprise a fluid permeable support member for supporting the semi-permeable membrane in the flow chamber. The support member may constitute a base portion of the flow chamber, the arrangement being such that feed fluid entering the flow chamber passes at least in part
5 through the support member. The support member may be of any suitable porous material such as high-density polyethylene, stainless steel, brass, finely woven fiber or the like. The support member may include pores of pore sizes between 10 and 150 μm .

10 The monitoring unit further may include spacer means for spacing the semi-permeable membrane from the support member so as to provide a flow space between the membrane and the support member, or between adjacent membranes on the support member. The monitoring unit may accommodate different spacers that vary in thickness and shape, the arrangement being such
15 that different spacers influence fluid dynamics of the feed fluid flowing across the semi-permeable membrane. So, for example, the monitoring unit may include a spacer that is locatable intermediate the semi-permeable membrane and the support member that is similar to a permeate-side spacer generally used in construction of spiral wrap elements. Also, for example, the monitoring unit may
20 include a feed-side spacer similar to that used in construction of spiral elements in use, wherein the feed-side spacer may be locatable on top of the semi-permeable membrane. It will be appreciated that specific spacer configurations affect the adsorption kinetics of fouling substances in the feed fluid and since the

monitoring unit has the potential to include different types of spacers, it includes the expanded potential for using the same to evaluate spacer technology.

The fluid outlet may be arranged in fluid communication with the support member
5 such that fluid that has passed through the membrane and the support member exits the monitoring unit through the fluid outlet. The fluid outlet may be arranged in fluid communication with a suitable conduit for passing the fluid through the water purification system.

10 The inspection window may be oriented substantially parallel to and somewhat spaced from the support member, the arrangement being such that the flow chamber is defined intermediate the support member and the inspection window. The inspection window may be of any suitable transparent material, such as plastics, Perspex, glass or the like, and may be characterized therein that it can
15 withstand a pressure of at least between 40 and 50 bar.

The monitoring unit may include regulating means for regulating flow across the membrane, as well as fluid pressure in the unit. Particularly, the regulating means may be at least one valve suitably arranged for regulating the fluid
20 pressure interval intermediate the feed fluid inlet and the feed fluid outlet. In one form of the invention, the monitoring unit may include at least one feed fluid inlet valve operatively associated with the feed fluid inlet. The monitoring unit also may include a feed fluid outlet valve operatively associated with the feed fluid

outlet of the flow chamber. It is envisaged that the fluid outlet adjacent the support member also may include a suitable fluid outlet valve.

In use, the regulating means may permit repeatable or standard conditions, such
5 as a constant cross-flow velocity and fluid pressure. By maintaining flow and pressure constant through the monitoring unit, flux or passage of pure water through the semi-permeable membrane can be measured. Any deviation in the flux through the membrane can then be attributed to adsorption of impurities onto the membrane (fouling or biofouling), which changes the permeability
10 characteristic of the membrane.

In one form of the invention, the monitoring unit may operatively be associated with pumping means for further manipulating fluid pressure in the monitoring unit. More particularly, the monitoring unit may operatively be associated with a
15 positive displacement pump arranged in-line with the monitoring unit and suitable for maintaining the fluid pressure interval intermediate the feed fluid inlet and outlet of the flow chamber.

The monitoring unit further may include flow distribution means. The flow
20 distribution means may be in the form of a manifold dimensioned for preventing turbulence within the flow chamber and for effecting homogenous fluid flow.

In one form of the invention, the monitoring unit may include an inlet manifold arranged intermediate the feed fluid inlet and the flow chamber for regulating flow of feed fluid into the flow chamber.

- 5 The monitoring unit also may include an outlet manifold located intermediate the flow chamber and the feed fluid outlet. The outlet manifold may be arranged such that it prevents areas of decreased flow in the flow chamber, so as to prevent preferential foulant adsorption or biological growth. The manifolds also may be arranged so as to permit reverse flow through the monitoring unit for
- 10 evaluating the effectiveness of back flushing on removal of impurities adsorbed onto the membranes.

- The monitoring unit further may comprise a casing. The casing may include top cover means and bottom cover means that releasably may be connected to each
- 15 other in fluid-tight and pressure-tight engagement, the arrangement being such that the inspection window, flow chamber and support member are located substantially intermediate the top and bottom cover means. The casing may be of stainless steel or the like suitable material.

- 20 The top cover means may comprise a metallic frame dimensioned so as at least partially to frame the inspection window. The bottom cover means may comprise a metallic sheet recessed at least partially to accommodate the flow chamber, the support member and the fluid outlet.

10650000 030500
The monitoring unit may be adapted for monitoring fouling of a semi-permeable membrane during operation of a water purification system. In particular, the monitoring unit may be characterized therein that it comprises the potential of simulating conventional fluid dynamics associated with these types of membranes across the spacer means and support member. Consequently, the monitoring unit may be dimensioned such that conventional operating conditions of the water purification system are simulated in the monitoring unit. Particularly, the monitoring unit may operate at a fluid pressure corresponding to that of the water purification system. More particularly, the monitoring unit may operate at a fluid pressure of between 40 and 50 bar.

The monitoring unit may be located inline with a conventional reverse osmosis water purification system. The monitoring unit particularly may be adapted for monitoring fouling of a semi-permeable spiral membrane in a spiral reverse osmosis water purification system. In this form of the invention, the monitoring unit may be located intermediate a feed fluid tank and a spiral membrane plant of the spiral reverse osmosis water purification system.

According to another aspect of the invention there is provided a method of monitoring fouling of a semi-permeable membrane in a water purification system, the method comprising the steps of providing a monitoring unit according to the invention; placing at least one semi-permeable test membrane on the fluid permeable support member; effecting at least partial passage of feed fluid

through the test membrane; and visually monitoring fouling of the test membrane through the inspection window as an indicating means for determining fouling of the semi-permeable membrane in the water purification system.

- 5 The method may concern monitoring fouling of the semi-permeable membrane during operation of the water purification system. Consequently, the method may comprise the step of effecting at least partial passage of feed fluid through the membrane under conventional system operating conditions. The method particularly may concern monitoring fouling of a semi-permeable spiral
- 10 membrane in a spiral reverse osmosis water purification system.

- The test membrane may removably be placed on the support member. The test membrane may be spaced from the support member by means of spacer means. A number of test membranes may be placed on the support member in spaced
- 15 orientation relative to each other.

- The test membrane may be any suitable flat-sheet semi-permeable membrane, such as a micro-filtration, ultra-filtration, nanno-filtration or the like reverse osmosis membrane. In particular, any type of flat-sheet semi-permeable
- 20 membrane associated with a polymeric support material may be used in the monitoring unit. Different types of polymeric materials used for the construction of these membranes may be used.

Fouling of the test membrane also may be monitored by means of suitable monitoring equipment, such as by means of laser beam or infrared refraction, or sound acoustics.

- 5 According to yet a further aspect of the invention there is provided the use of a monitoring unit including a semi-permeable test membrane for evaluating one or more of the following operating parameters in a water purification system namely the efficiency of different types of chemicals utilized in the system, such as anti-scalants, biocides and anti-fouling chemicals; the effect of using different
- 10 membranes and/or associated spacer means in the water purification system on the operating efficiency of the system; and efficiency of different membrane cleaning methods.

- According to yet another aspect of the invention there is provided the use of a
- 15 monitoring unit according to the invention for evaluating one or more of the following parameters in a spiral membrane reverse osmosis water purification system namely fouling of the spiral membrane; the efficiency of different types of chemicals utilized in the system, such as anti-scalants, biocides and anti-fouling chemicals; the effect of using different membranes and/or associated spacer
- 20 means in the water purification system on the operating efficiency of the system; and efficiency of different membrane cleaning methods.

According to yet a further aspect of the invention there is provided a water purification system including at least one water-cleaning unit, the water purification system characterized therein that it includes a monitoring unit that comprises a flow chamber having an inlet for permitting ingress of a feed fluid
5 into the flow chamber; a fluid permeable support member for supporting the semi-permeable membrane in the flow chamber; at least one fluid outlet arranged in fluid communication with the support member for permitting egress of fluid from the monitoring unit after having passed through the membrane; and an inspection window for permitting visual inspection of the semi-permeable
10 membrane in use supported by the support member.

According to yet a further aspect of the invention there is provided the use of a monitoring unit according to the invention in a water purification system.

15 **Specific embodiment of the invention**

Without limiting the scope thereof, one embodiment of the invention will now be described by way of example only and with reference to the accompanying drawings wherein –

- 20 Figure 1 is a cross-sectional side view of a monitoring unit according to one embodiment of the invention;
Figure 2 is a plan view of the monitoring unit of Figure 1; and
Figure 3 is a perspective view of the monitoring unit of Figures 1 and 2.

A monitoring unit according to the invention is generally designated by reference numeral 10. The monitoring unit 10 is adapted for use in a water purification system that includes at least one water-cleaning unit wherein the water-cleaning unit comprises at least one membrane for cleaning water through reverse osmosis. Particularly, the monitoring unit 10 is adapted for monitoring the condition of a semi-permeable spiral membrane in a spiral membrane reverse osmosis water purification system by monitoring fouling of a semi-permeable test membrane 24 in the monitoring unit 10. It will be appreciated by those engaged in the industry that such a reverse osmosis water purification system often includes a series of successive water-cleaning units.

The monitoring unit 10 comprises a flow chamber 12 having a feed fluid inlet 14 for permitting ingress of a feed fluid into the flow chamber 12 and a feed fluid outlet 22 for permitting at least partial through-flow of the feed fluid through the flow chamber 12.

The flow chamber 12 is dimensioned such that a fluid pressure interval is defined intermediate the feed fluid inlet 14 and the feed fluid outlet 22. Particularly, fluid pressure at the feed fluid outlet 22 is less than that at the feed fluid inlet 14 such that, in use, feed fluid partly exits through the feed fluid outlet 22 of the flow chamber 12, and in part passes through the semi-permeable test membrane 24.

10090302 030606

The monitoring unit 10 also comprises a fluid permeable support member 16 for supporting the semi-permeable test membrane 24 in the flow chamber 12. The support member 16 is located in a stainless steel bottom plate 17 in which a receiving aperture is machined for receiving the support member 16 in use. The support member 16 is arranged in fluid communication with a fluid outlet 18 for permitting egress of fluid from the monitoring unit 10 after having passed through the membrane. The support member 16 is a substantially porous member constituting a base portion of the flow chamber 12. In particular, the arrangement is such that feed fluid entering the flow chamber 12 passes at least in part through the support member 16.

15 The semi-permeable test membrane 24 is spaced from the support member 16 by means of a number of intermediate spacers (not shown). In particular, the test membrane 24 has an exposed surface area of approximately 10cm x 30cm.

20 The monitoring unit 10 further comprises an inspection window 20 for permitting visual inspection of the semi-permeable test membrane 24 in use as supported by the support member 16. The inspection window 20 is oriented substantially parallel to and somewhat spaced from the support member 16 such that the flow chamber 12 is defined intermediate the support member 16 and the inspection window 20. The inspection window 20 is a sheet of any suitable transparent material, such as plastics, Perspex, glass or the like characterized therein that it is capable of withstanding a pressure of between 40 to 50 bar.

The support member 16 is arranged in fluid communication with a fluid outlet 18 which is located in the bottom plate 17, the arrangement being such that fluid that has passed through the test membrane 24 and the support member 16 exits the monitoring unit 10 through the fluid outlet 18. The fluid outlet 18 is arranged in fluid communication with a suitable conduit (not shown) for passing the fluid through the water purification system.

The monitoring unit 10 further includes regulating means for regulating fluid pressure in the monitoring unit 10. Particularly, the regulating means is a valve suitably arranged for regulating the fluid pressure interval intermediate the feed fluid inlet 14 and outlet 22.

The monitoring unit 10 further includes flow distribution means 28. The flow distribution means 28 is in the form of a manifold dimensioned for preventing turbulence within the flow chamber 12 and for effecting homogenous fluid flow. In the illustrated embodiment of the invention, the monitoring unit 10 includes an inlet manifold 28.1 arranged intermediate the feed fluid inlet 14 and the flow chamber 12 for regulating flow of feed fluid into the flow chamber 12. The monitoring unit 10 also includes an outlet manifold 28.2 located intermediate the flow chamber 12 and the feed fluid outlet 22.

The monitoring unit 10 further comprises a casing including top cover means 30 and bottom cover means 32 that are releasably connected to each other in fluid-

tight and pressure-tight engagement by means of bolts 34 extending from the bottom cover means 32 and protruding through the top cover means 30. At one end thereof the bolts 34 are secured in place by means of washers 36 and nuts 38 dimensioned to accommodate the bolts 34. In particular, the arrangement is
5 such that the inspection window 20, flow chamber 12 and support member 16 are located intermediate the top cover means 30 and bottom cover means 32. The casing is of stainless steel or the like suitable material.

The top cover means 30 comprises a metallic frame dimensioned so as at least
10 partially to frame the inspection window 20. The bottom cover means 32 comprises a metallic sheet recessed at least partially to accommodate the support member 16 and the fluid outlet 18.

It will be appreciated that many other embodiments of the invention may be
15 possible without departing from the spirit or scope of the invention as set out in the claims.